The ATACAMA project
Systematic search for Lyα nebulae

ATACAMA
A Tool seArChing for lArge lyMan Alpha nebula

Episode 1 : The Beginning

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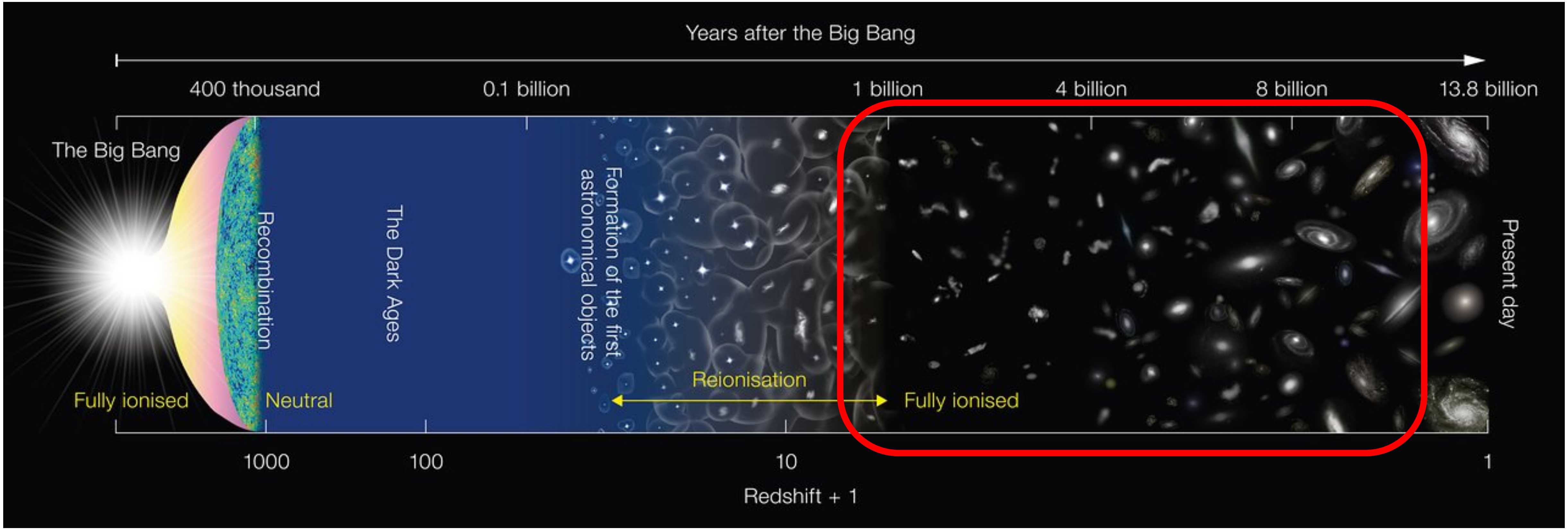
On behalf of the ATACAMA team.

Outline

- What do we know about LABs
- How do we find them ?
- Existing Surveys
- Objectives
- Method & Tool
- Studied Fields
- Preliminary Results
- Next steps

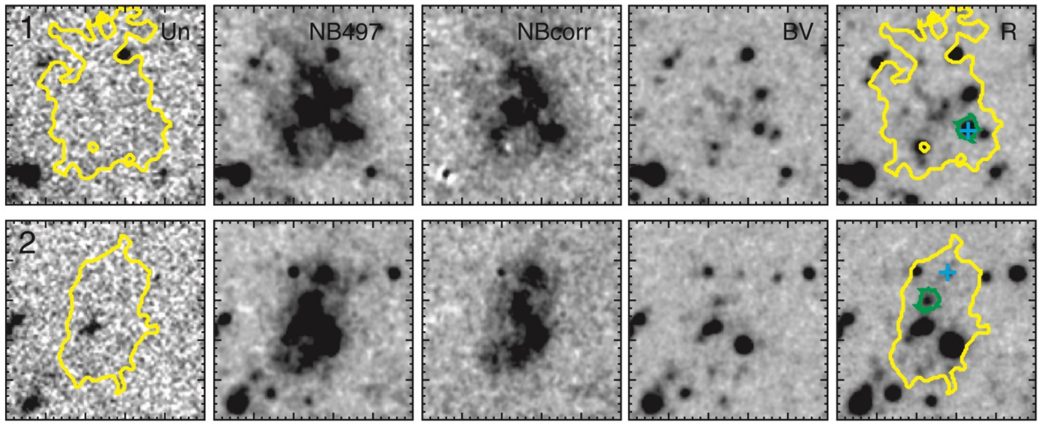
Context


Years after the Big Bang
400 thousand
0.1 billion
1 billion
4 billion
8 billion
13.8 billion
The Big Bang
Recombination
The Dark Ages
Formation of the first astronomical objects
Present day
Fully ionised
Neutral
Reionisation
Fully ionised
1000
100
10
1
Redshift + 1

What do we know about Lyα nebulae/blobs (LABs) ?

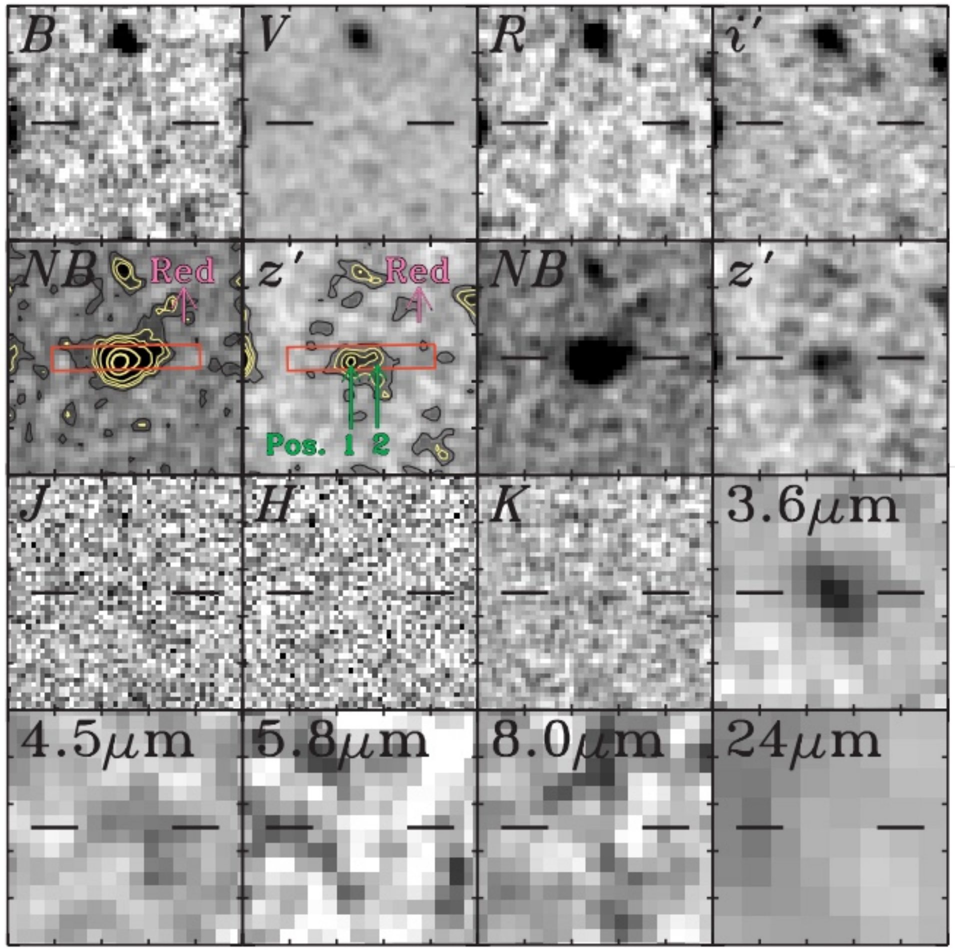
Extended (30 to 200 kpc)
Lyα-luminous (10^{43} to 10^{44} erg s^{-1})
Associated to a very diverse galaxy population
Usually in the dense environment of high-z star-forming galaxies
Various models to explain them

z=3.09 1) 222 $arcsec^2$. 2) 152 $arcsec^2$

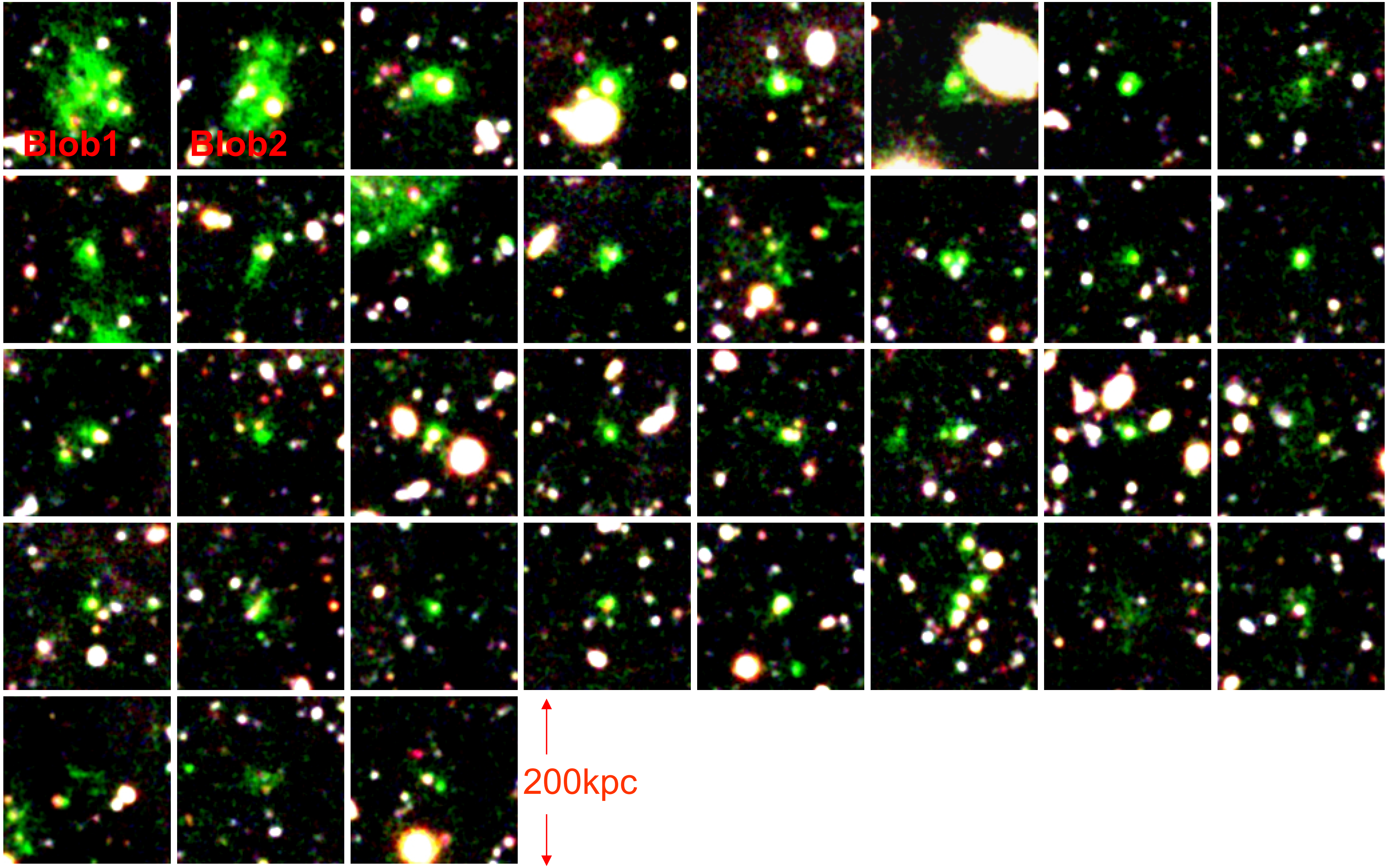


Matsuda et al. 2004

Himiko - z = 6.595 - 5.22 $arcsec^2$



Ouchi et al. 2009



35 Lyman alpha blobs have large varieties (Matsuda et al. 2004)

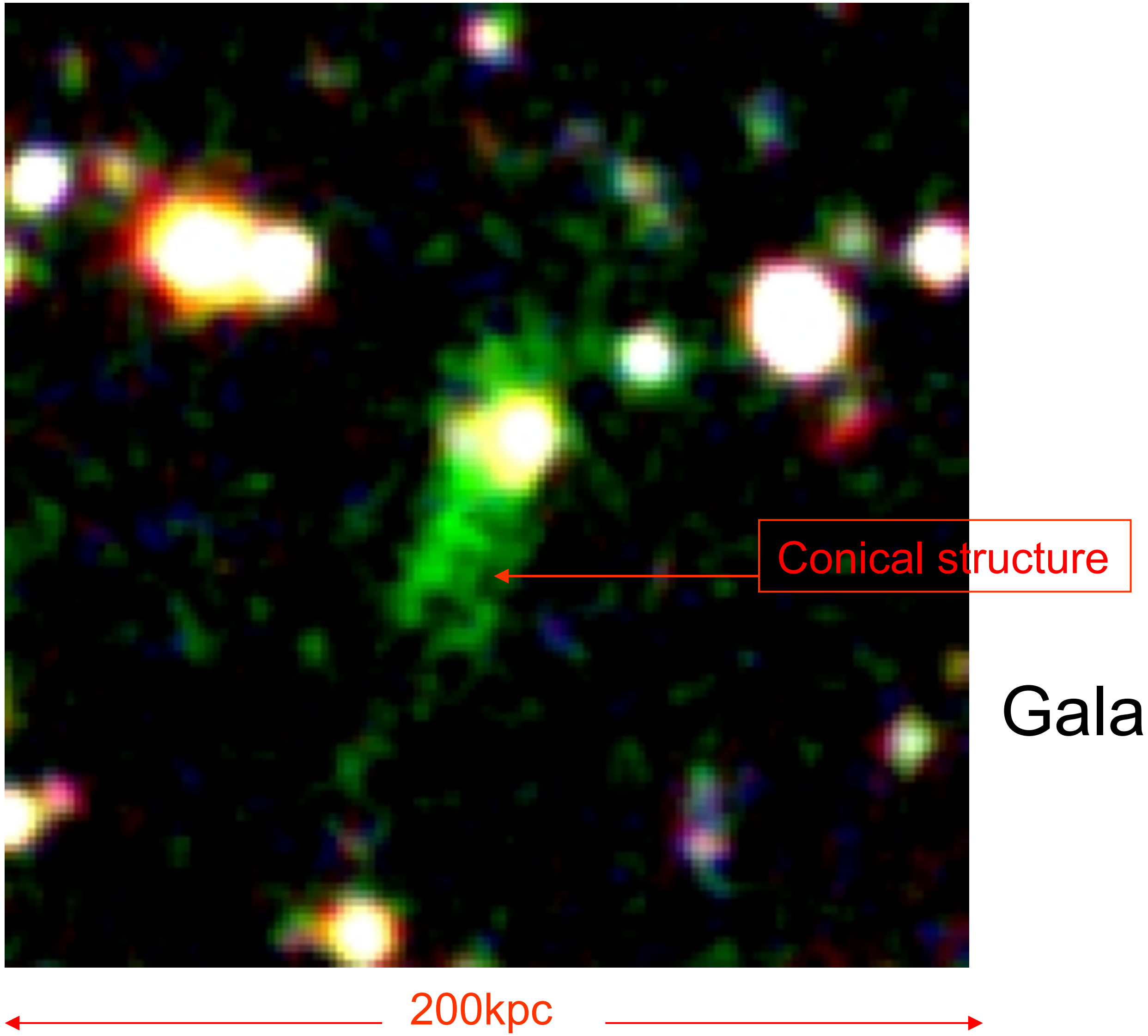
What do we know about Lyα nebulae/blobs (LABs) ?

- often been discovered in over-dense regions at $z \simeq 2$–3
- could be closely related to the galaxy environments
- associated with star-forming galaxies (SMGs, DRGs, LBGs)
- sites of ongoing massive galaxy formation and assembly
- linked to the formation mechanisms of central massive galaxies in galaxy protoclusters.
- extended gaseous structures around them are believed to be observational signs of large- scale gas flows (inflow/outflow)

What do we know about Lyα nebulae/blobs (LABs) ?

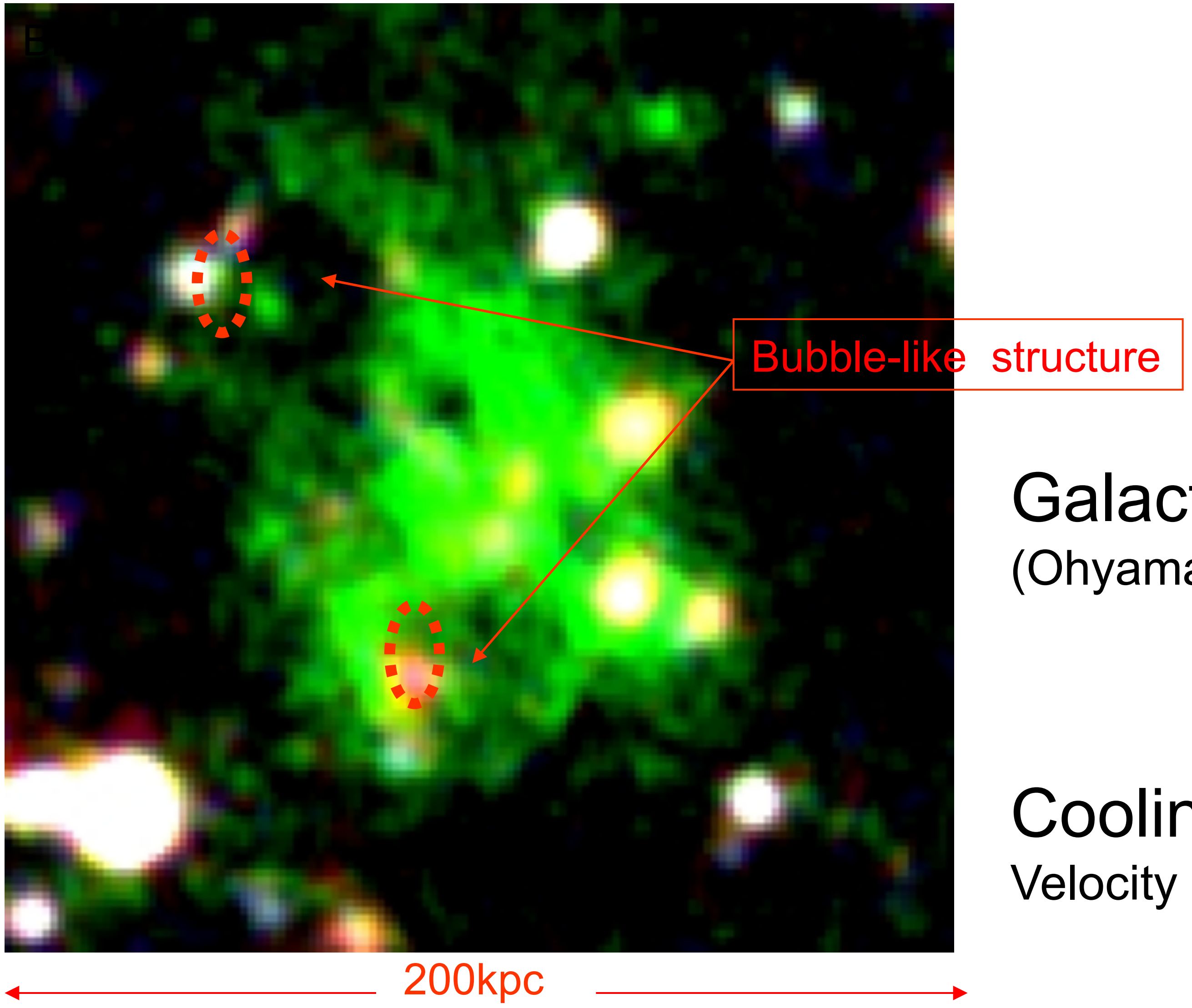
- The origins of LABs explained by several mechanisms:
  - resonant scattering of Lyα photons emitted from central sources in dense and extended neutral hydrogen
  - cooling radiation from gravitationally heated gas in collapsed halos
  - shock heating by galactic superwind originating from starbursts and/or AGN activity
  - galaxy major mergers
  - photoionization by external UV sources

What do we know about Lyα nebulae/blobs (LABs) ?



Galactic superwind?

What do we know about Lyα nebulae/blobs (LABs) ?

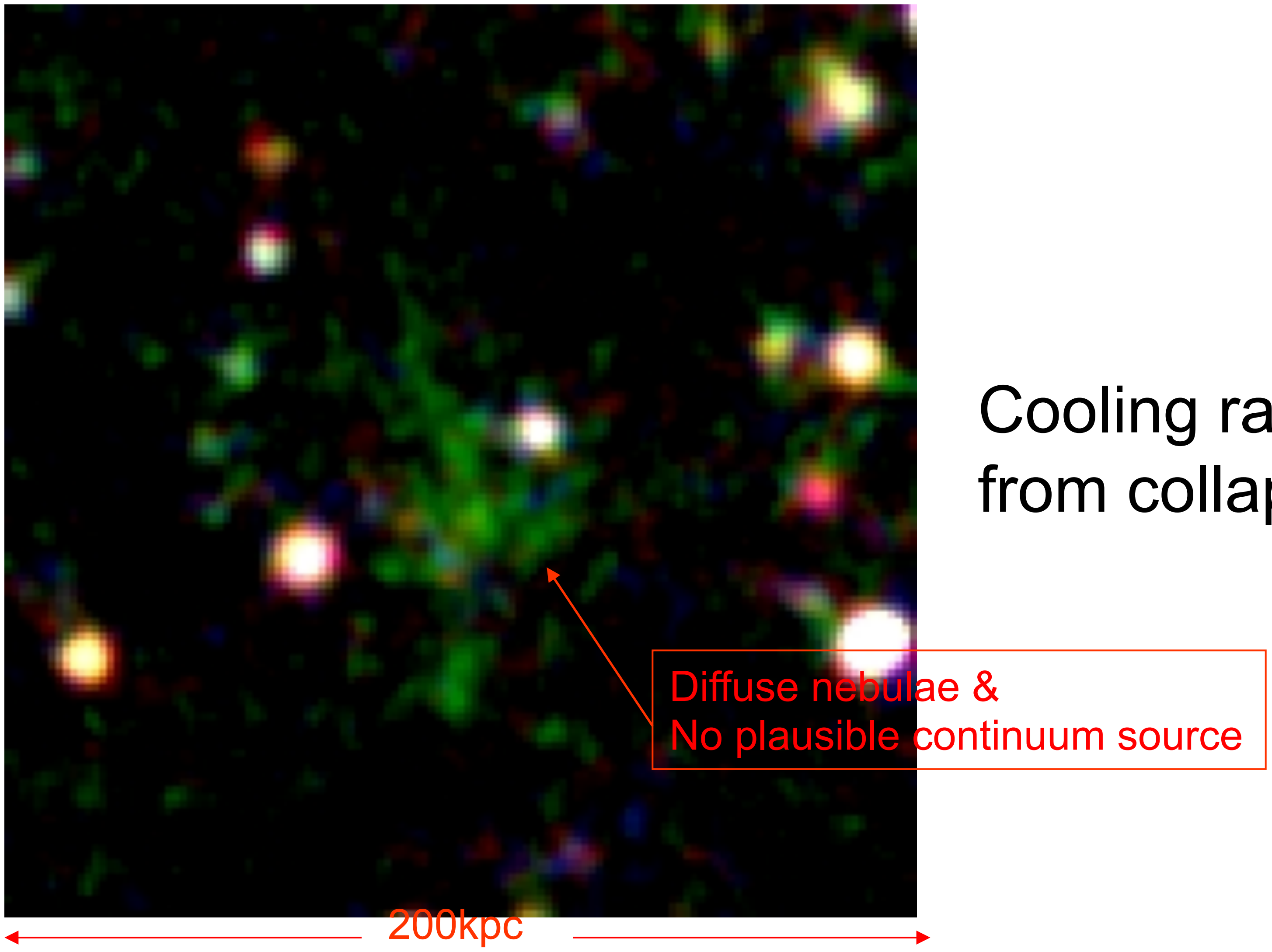


Galactic superwind?
(Ohyama et al. 2003)

or

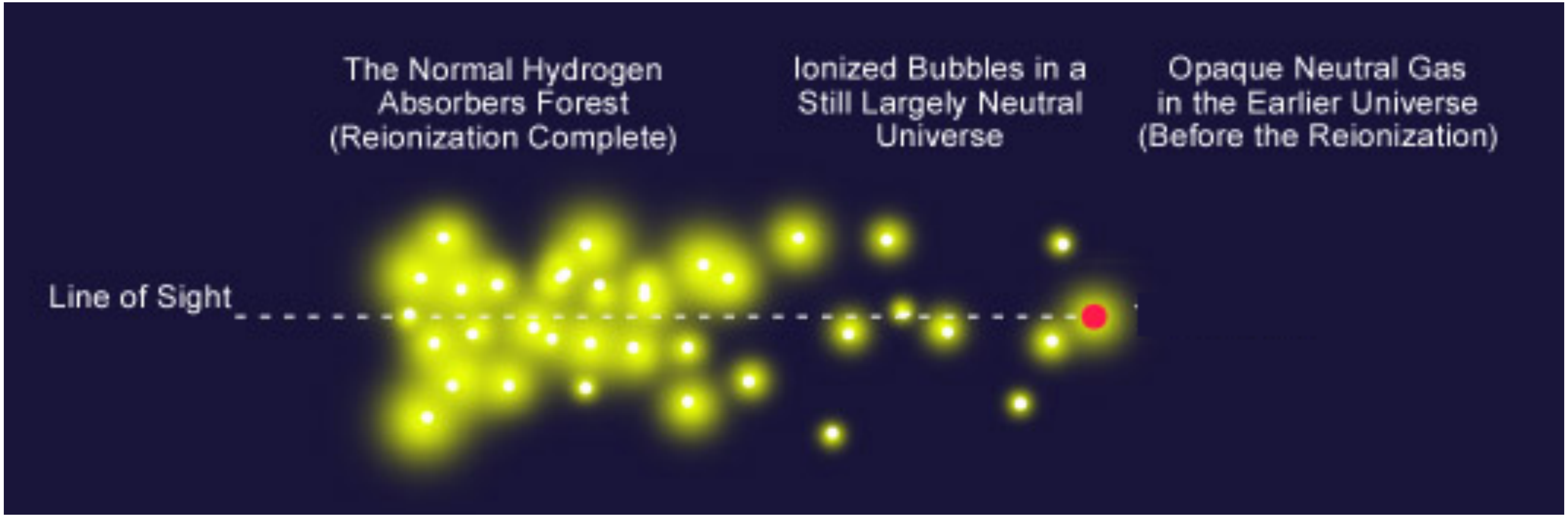
Cooling radiation?
Velocity structure is chaotic
(Bower et al. 2004)

What do we know about Lyα nebulae/blobs (LABs) ?



Cooling radiation from collapsing halo?

Method : How to search for Lymanα ?

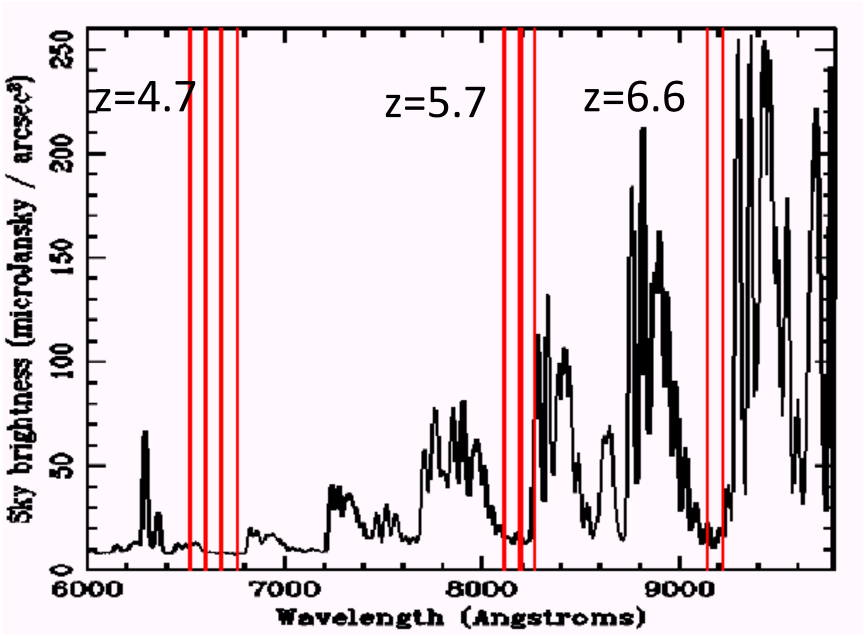


Two main techniques :

- Narrow-Band technique
- Lyman Break technique

Method : How to search for Lymanα ?

Narrow-Band technique



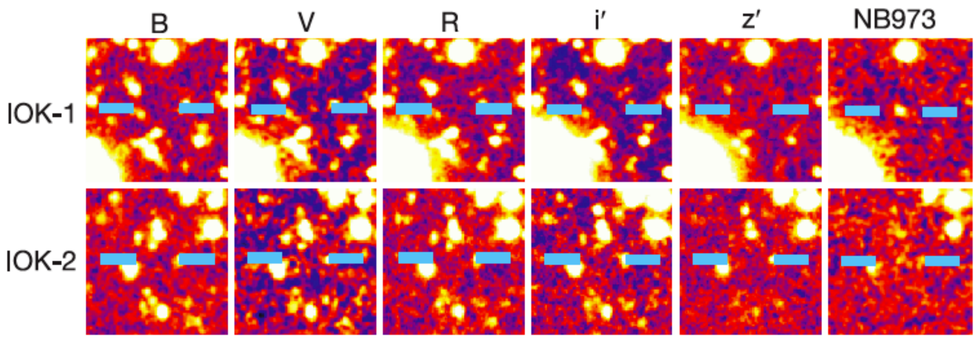
Narrow-band filters sample dark region between sky lines

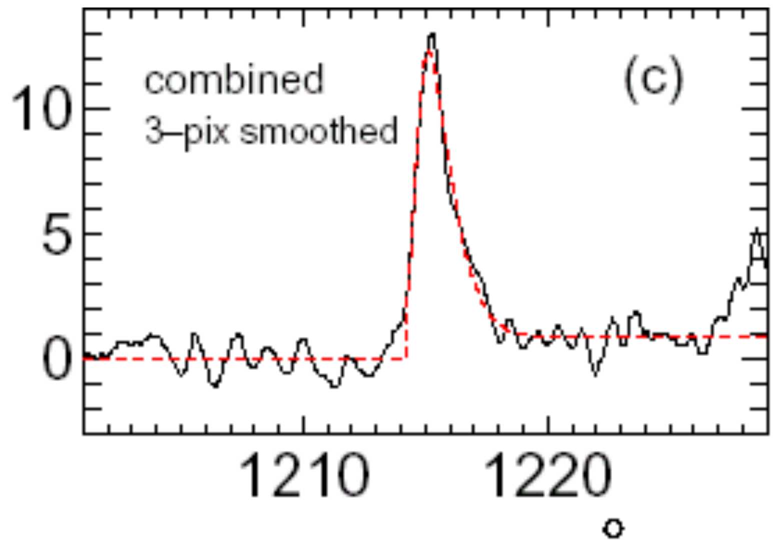
Clean selection method if combined with deep multi-wavelength imaging data

However:

Selects over very narrow redshift range

=> large area detectors needed



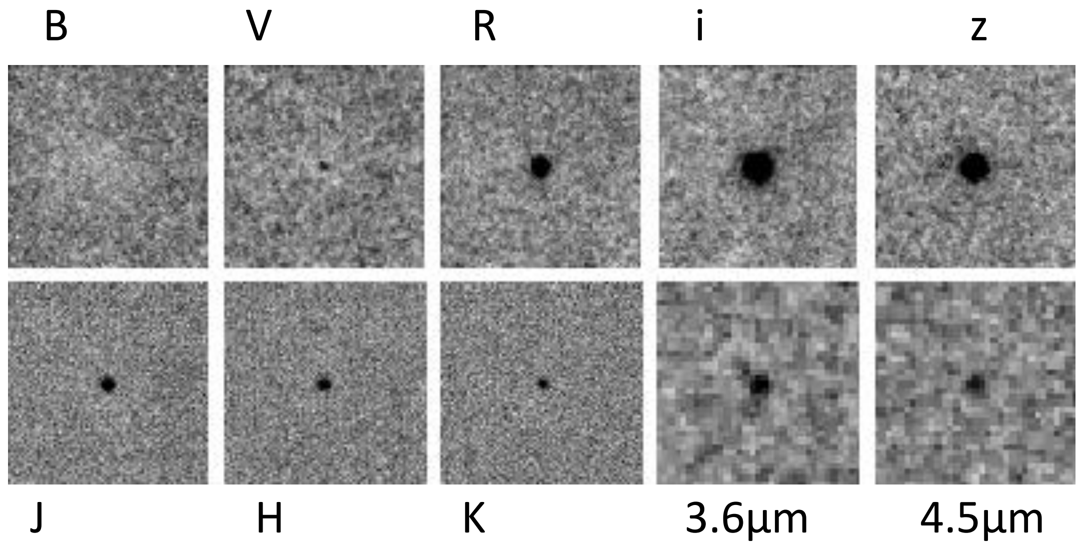


Method : How to search for Lymanα ?
Lyman Break technique

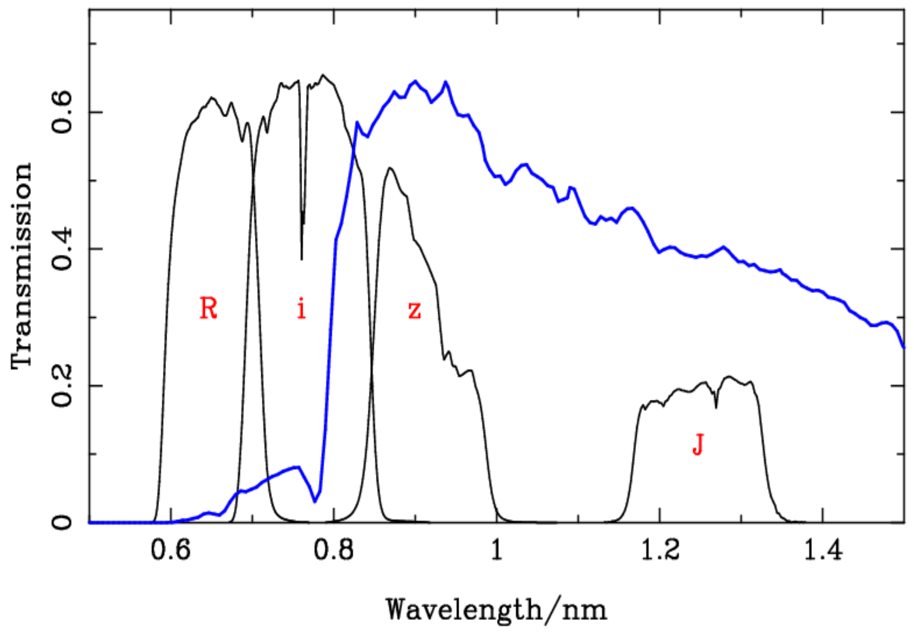
Radiation at higher energies than the Lyman limit at 912 Å almost completely absorbed by neutral

Emitted spectrum is bright at wavelengths longer than 912 Å, but imperceptible at shorter wavelengths

Drop-out technique to find the position of the Lyman limit.



McLure et al. (2008)



Existing surveys

- Yang et al. 2010 : NB search z=2.3
  - 1.2 deg ^{2}
  - 25 candidates – 5 spectroscopically confirmed
  - Area 10-60 arcsec^2 – L(Ly) 0.7-8 1043 erg s^{-1}

- Matsuda et al. 2011 : NB search z=3.1
  - 2.12 deg^2
  - 14 candidates
  - Area 28-181 arcsec^2 L(Ly) 0.8-20 1043erg s^{-1}

- Arrigoni-Battaia et al. 2018 : IFS search z=3.17
  - 61 arcmin^2
  - 61 LABs : around QSOs

Existing surveys

- Shibuya et al. 2018 : NB search at z=5.7 and z=6.6
  - 13.8 deg^2 and 21.2 deg^2
  - 11 candidates – 6 spectroscopically confirmed

- Wisotzki et al. 2017 : IFS search z=3-6
  - MUSE GTO
  - 26 LABs

and more….

⟹ Need to homogenize the selection method for LABS z~2-7 to draw firm conclusion on their evolution.

⟹ Basic properties such as their number density, clustering, and large-scale environment are still poorly constrained.

Objectives

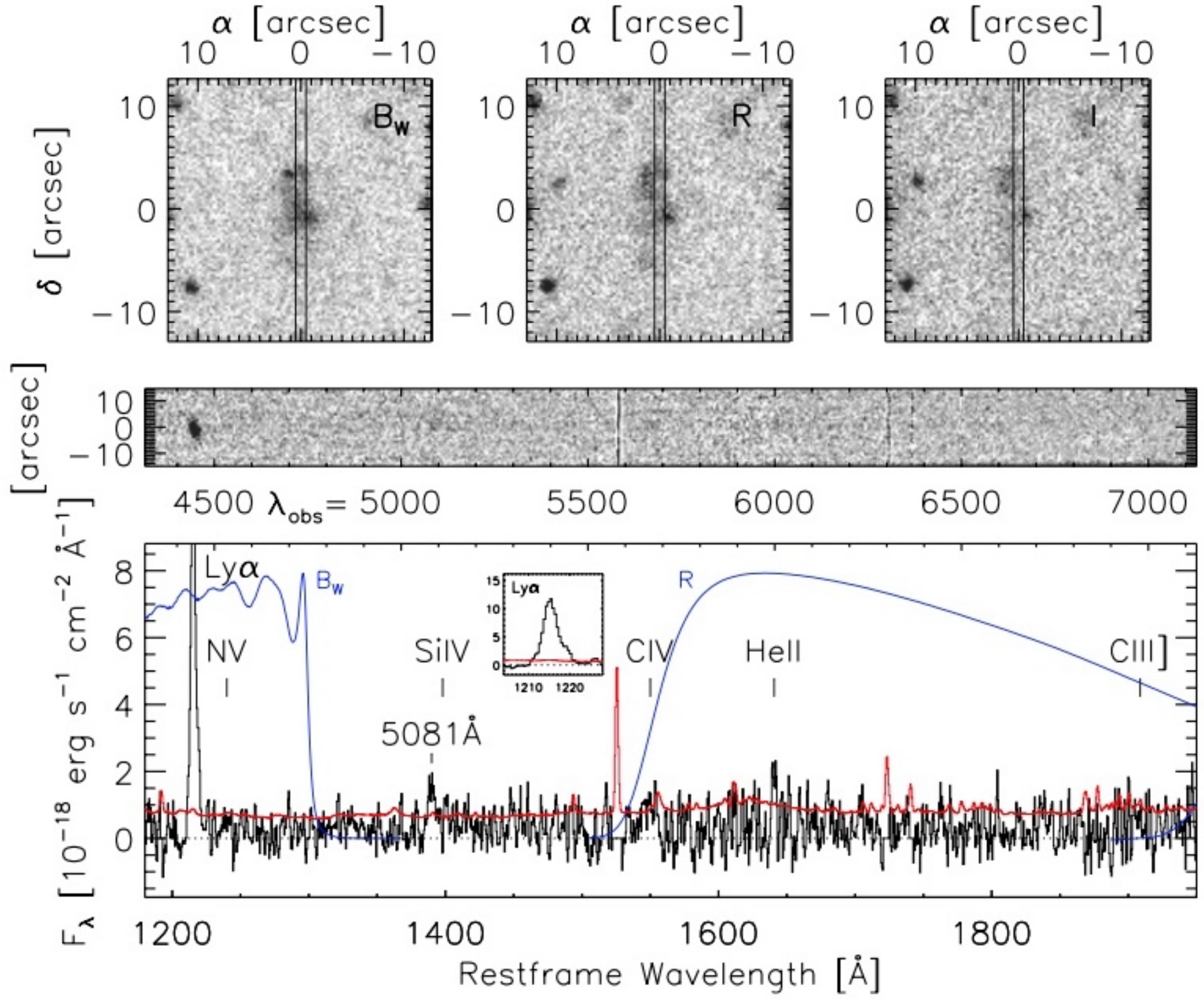
- Questions we want to answer
  - The formation mechanisms of these rare Lyα-emitting populations are still controversial due to the small statistics
  - Nature and origins : Can we find a consensus?
  - Outflow/Inflow to be probed

BUT :

- NB search for high redshift ELG : observationally expensive
- Highly competitive to obtain time on VLT/MUSE
- Archival data not used at their maximum potential

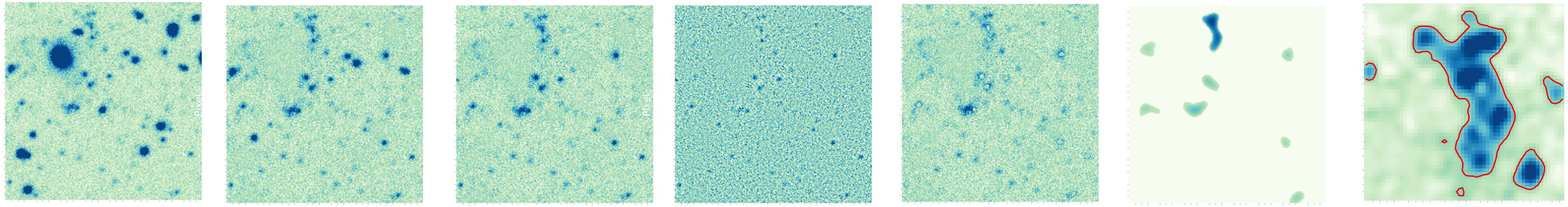
ATACAMA Strategy

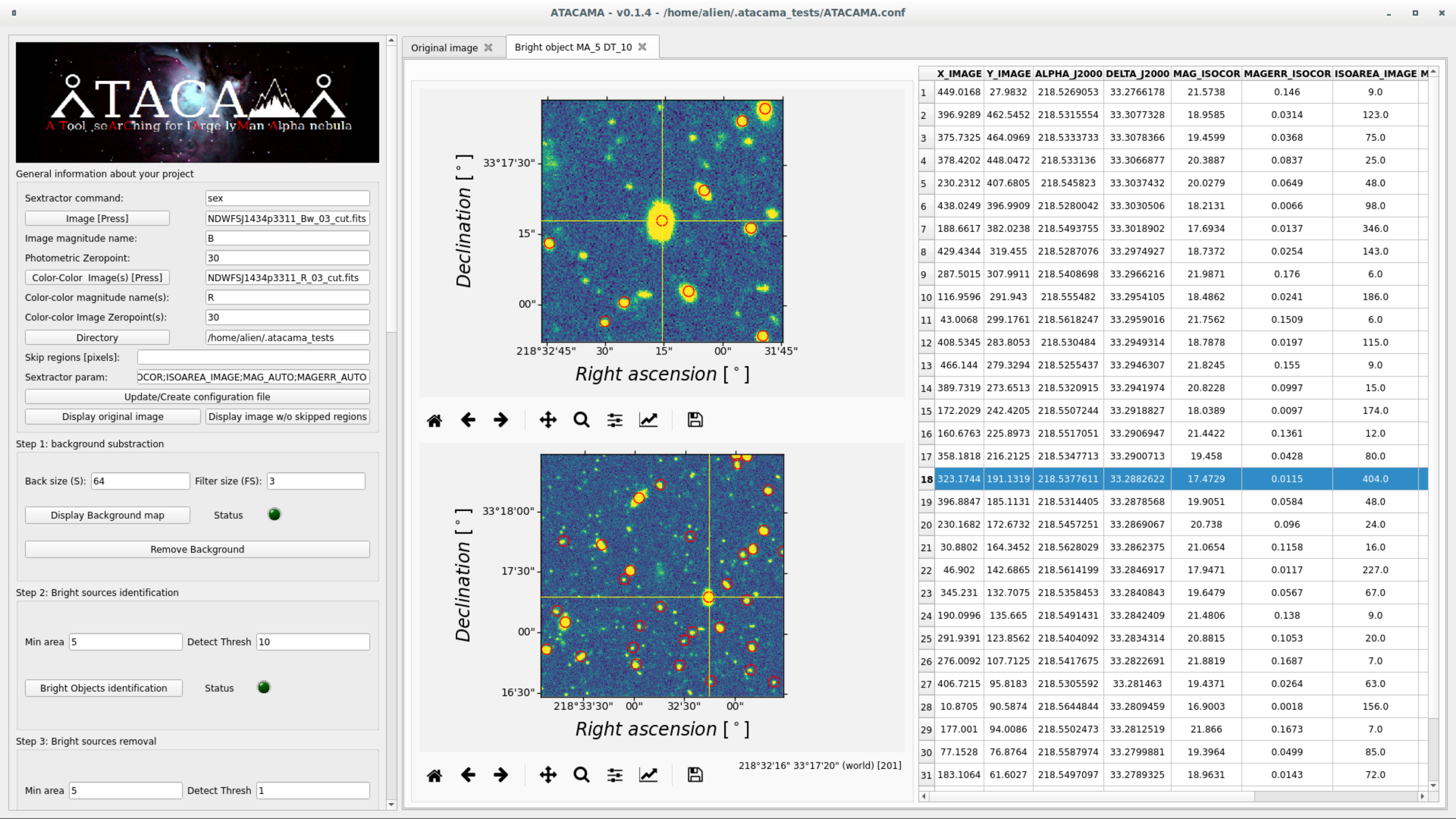
- Based on Prescott et al. 2012
- NOAO Deep Wide-Field Survey Boötes field
- Bw, R, I filters
  Search in Bw.
- Successful method :
  Prescott et al. 2013
- Success rate ~ 27%



Our Method & Tool

- Interactive GUI communicating with the Sextractor : open source python 3.5
- Clean the photometric field from bright, intermediate and faint targets
- Identify, through a wavelet decomposition, the largest faint structures in the field.
- Select and Inspect each candidates : create CMD, record catalogs with colors to create a final sample
- Each step can be tuned separately which makes the process totally transparent.





	X_IMAGE	Y_IMAGE	ALPHA_J2000	DELTA_J2000	MAG_ISOCOR	MAGERR_ISOCOR	ISOAREA_IMAGE	M
1	449.0168	27.9832	218.5269053	33.2766178	21.5738	0.146	9.0	
2	396.9289	462.5452	218.5315554	33.3077328	18.9585	0.0314	123.0	
3	375.7325	464.0969	218.5333733	33.3078366	19.4599	0.0368	75.0	
4	378.4202	448.0472	218.533136	33.3066877	20.3887	0.0837	25.0	
5	230.2312	407.6805	218.545823	33.3037432	20.0279	0.0649	48.0	
6	438.0249	396.9909	218.5280042	33.3030506	18.2131	0.0066	98.0	
7	188.6617	382.0238	218.5493755	33.3018902	17.6934	0.0137	346.0	
8	429.4344	319.455	218.5287076	33.2974927	18.7372	0.0254	143.0	
9	287.5015	307.9911	218.5408698	33.2966216	21.9871	0.176	6.0	
10	116.9596	291.943	218.555482	33.2954105	18.4862	0.0241	186.0	
11	43.0068	299.1761	218.5618247	33.2959016	21.7562	0.1509	6.0	
12	408.5345	283.8053	218.530484	33.2949314	18.7878	0.0197	115.0	
13	466.144	279.3294	218.5255437	33.2946307	21.8245	0.155	9.0	
14	389.7319	273.6513	218.5320915	33.2941974	20.8228	0.0997	15.0	
15	172.2029	242.4205	218.5507244	33.2918827	18.0389	0.0097	174.0	
16	160.6763	225.8973	218.5517051	33.2906947	21.4422	0.1361	12.0	
17	358.1818	216.2125	218.5347713	33.2900713	19.458	0.0428	80.0	
18	323.1744	191.1319	218.5377611	33.2882622	17.4729	0.0115	404.0	
19	396.8847	185.1131	218.5314405	33.2878568	19.9051	0.0584	48.0	
20	230.1682	172.6732	218.5457251	33.2869067	20.738	0.096	24.0	
21	30.8802	164.3452	218.5628029	33.2862375	21.0654	0.1158	16.0	
22	46.902	142.6865	218.5614199	33.2846917	17.9471	0.0117	227.0	
23	345.231	132.7075	218.5358453	33.2840843	19.6479	0.0567	67.0	
24	190.0996	135.665	218.5491431	33.2842409	21.4806	0.138	9.0	
25	291.9391	123.8562	218.5404092	33.2834314	20.8815	0.1053	20.0	
26	276.0092	107.7125	218.5417675	33.2822691	21.8819	0.1687	7.0	
27	406.7215	95.8183	218.5305592	33.281463	19.4371	0.0264	63.0	
28	10.8705	90.5874	218.5644844	33.2809459	16.9003	0.0018	156.0	
29	177.001	94.0086	218.5502473	33.2812519	21.866	0.1673	7.0	
30	77.1528	76.8764	218.5587974	33.2799881	19.3964	0.0499	85.0	
31	183.1064	61.6027	218.5497097	33.2789325	18.9631	0.0143	72.0	

Limitations of the method

- Requires spectroscopic observations
  ⟶ target only the largest and brightest candidates

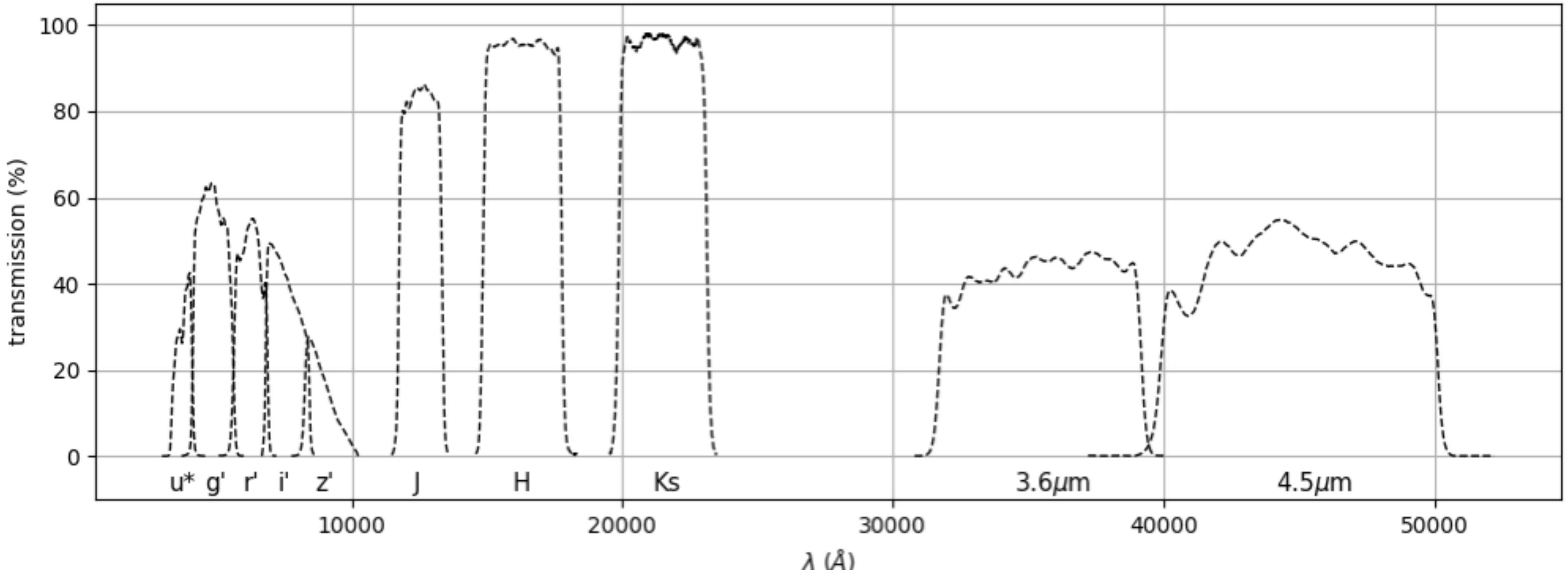
- Possible interlopers :
  - OII,OIII,Hα emitters,
    but OII emitters have redder colors than Lyα emitters
    ⟶ importance of having multi-wavelength data available
  - Spatially extended continuum-only sources
  - Low Surface Brightness galaxies

Data set

1 deg^2 of COSMOS field: deep multi-wavelength data available

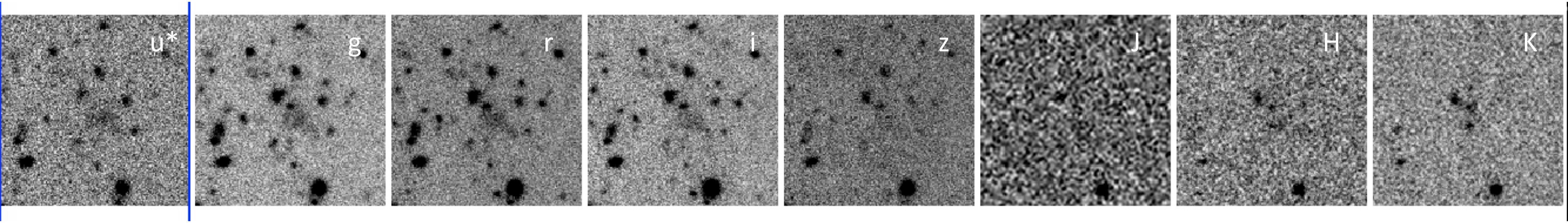
CFHT-LS T0007 (MegaCam); WIRDS T0002 (WIRCam); SCOSMOS (Spitzer/IRAC + Spitzer/MIPS) data releases

Filters	Redshift range	Surface Brightness Limits (mag arcsec^{-2})
u*	1.7 < z < 2.5	26.37 ± 0.10
g	2.3 < z < 3.8	26.02 ± 0.10
r	3.5 < z < 4.8	25.60 ± 0.10
i	4.5 < z < 6.2	25.24 ± 0.10
z	5.6 < z < 7.6	25.04 ± 0.10



Preliminary Results

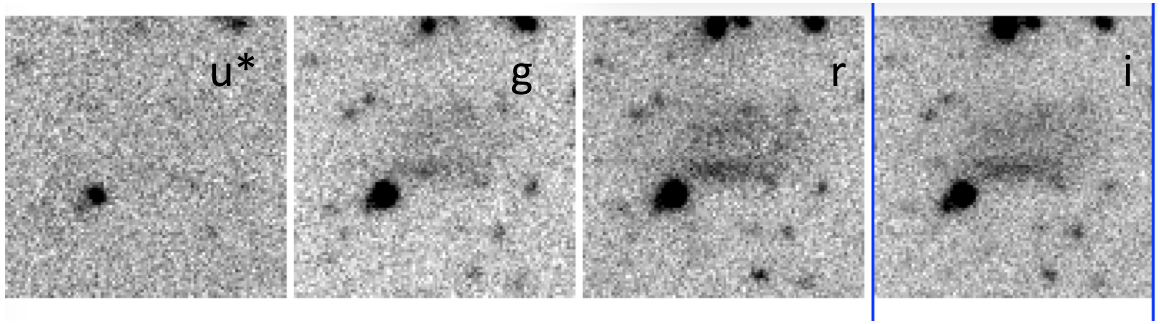
- Focused on 7 sub-fields
- Search for candidates in u, g and r-bands.
- Color selection criteria to be defined and probed for each BB.
- Size range: targeting the largest ones.
  But still need to take in account the size evolution of LAEs with redshift (Shibuya et al. 2018)

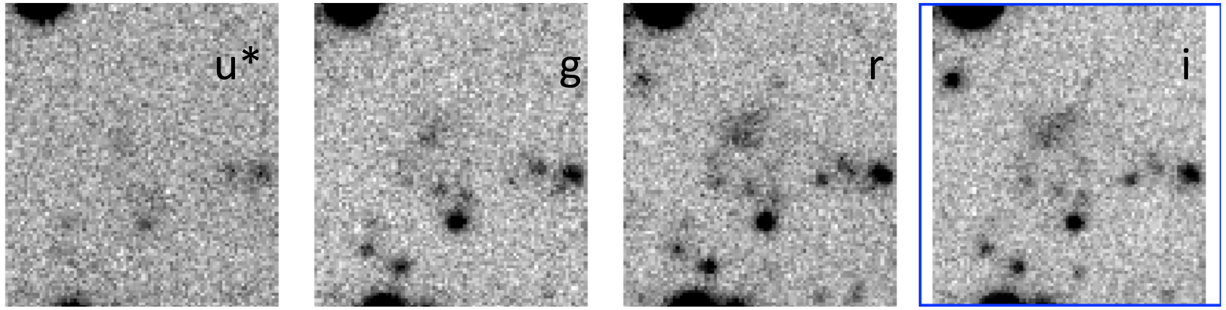


P. Hibon et al. in prep

Next steps

- Cross-correlation with photometric redshift catalog (Laigle et al. 2018)
  ⟶ Refine the color criteria
- SED production
- Visual inspection : star halo, galaxy halo, tidal arm, group, diffuse





- Very important to do a rigorous selection.
- Expect 1/5 from the finale catalog to be spectroscopically confirmed.

Exciting Results

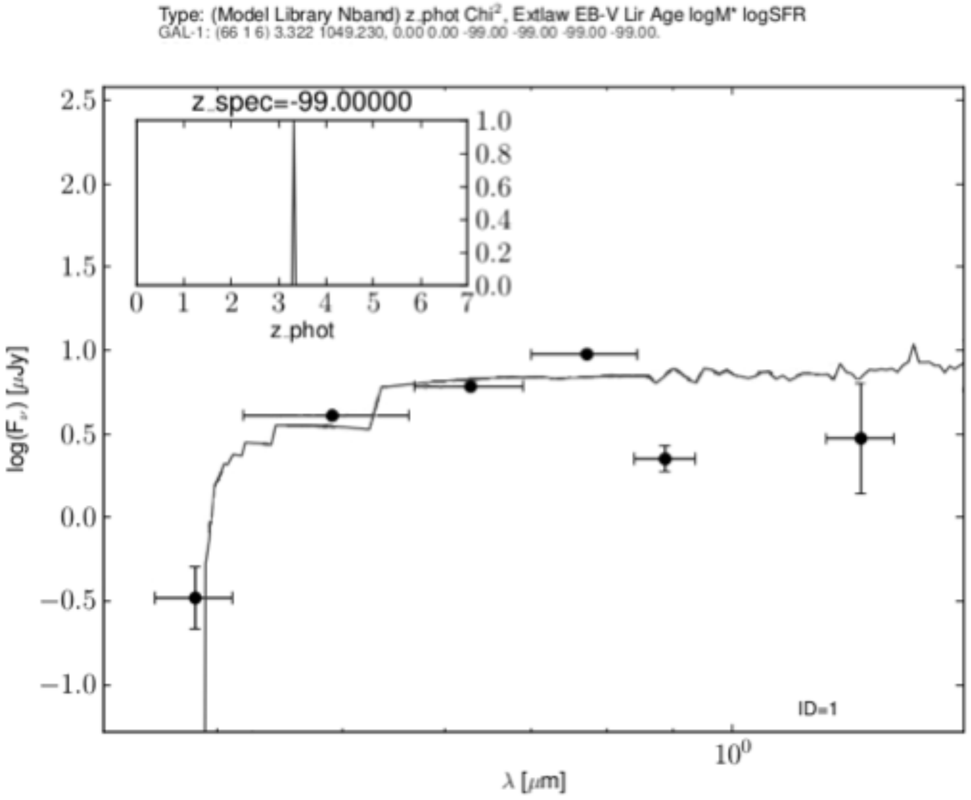
No match in COSMOS2015

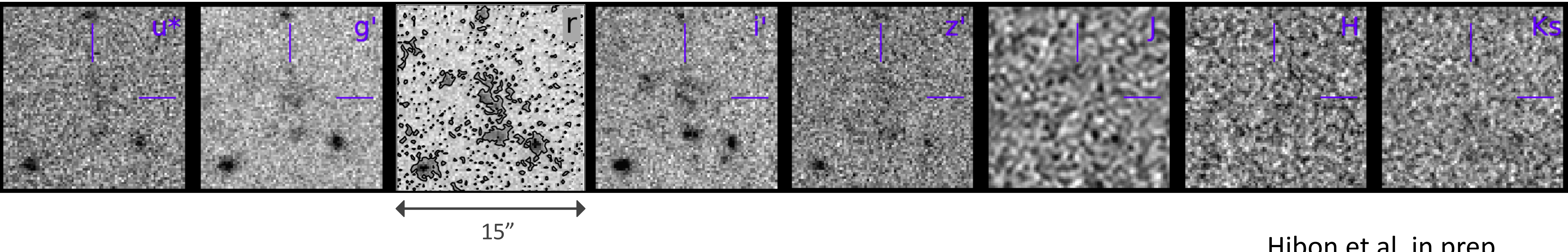
z_{phot} (LePhare) ≈ 3.2

29.4 $arcsec^2$

28 kpc x 59 kpc

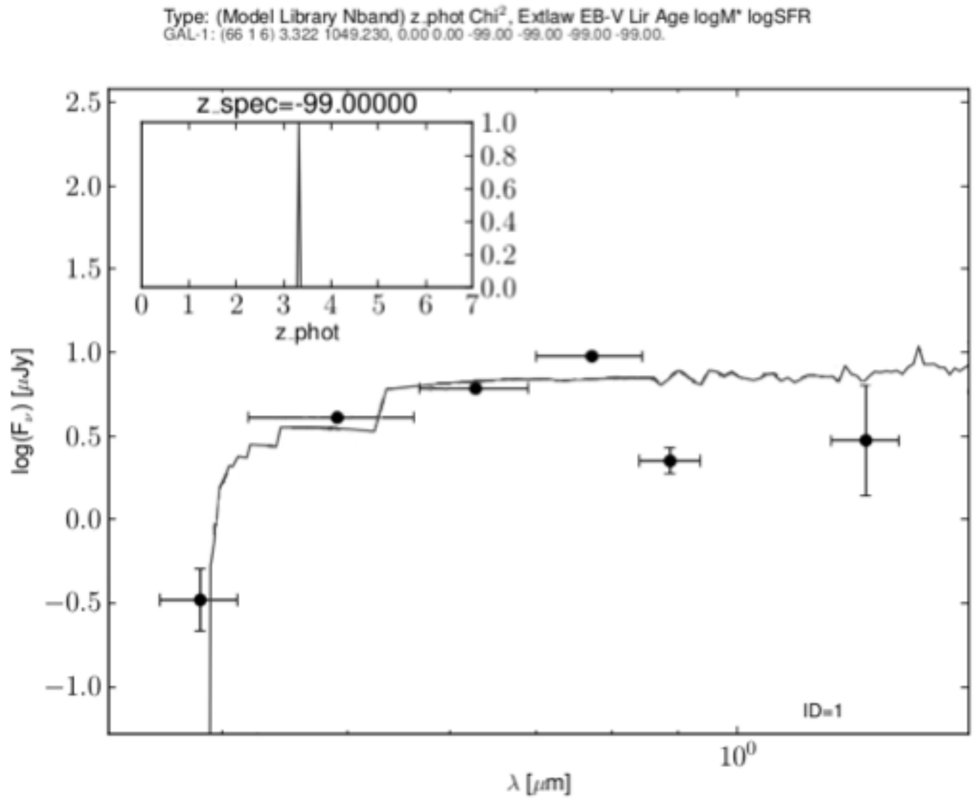
DDT proposal: XSHOOTER for spectroscopic confirmat





Hibon et al. in prep.

Exciting Results



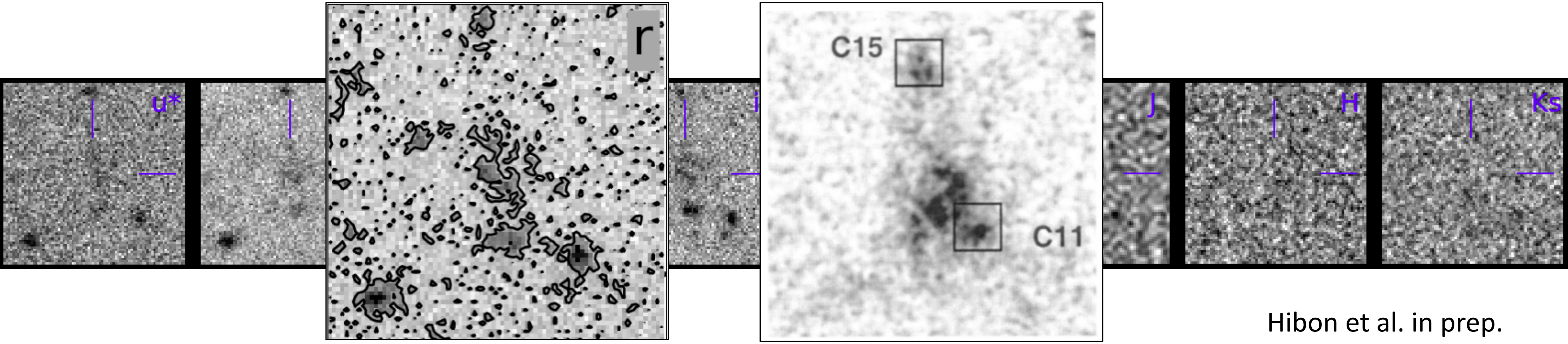
No match in COSMOS2015

z_{phot} (LePhare) ≈ 3.2

29.4 arcsec^2

28 kpc x 59 kpc

Similar structure to blob1 (Steidel et al. 2000)



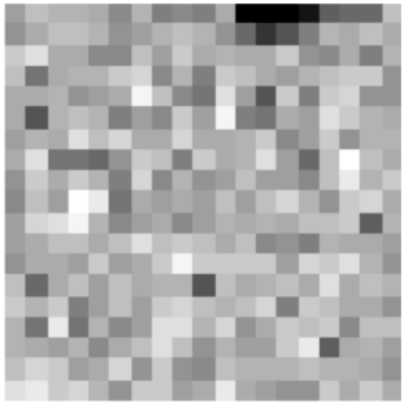
Hibon et al. in prep.

Exciting Results

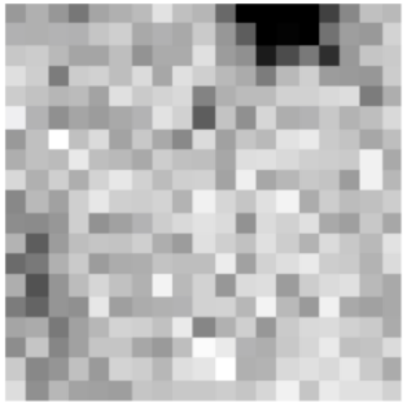
To understand its origin and possible counterparts :

GALEX :

FUV

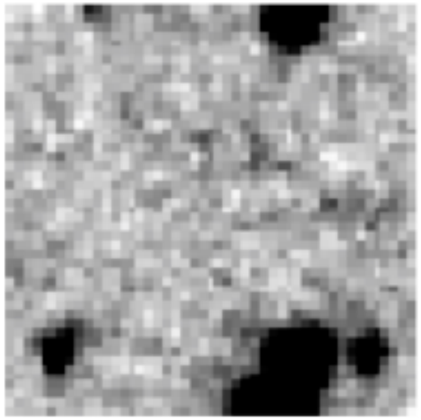


NUV

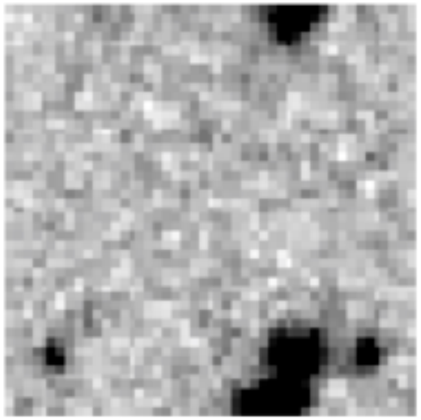


Spitzer :

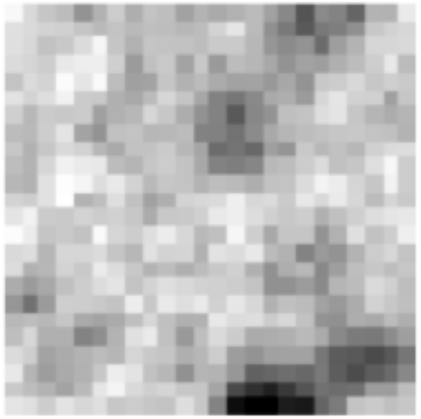
3.6microns

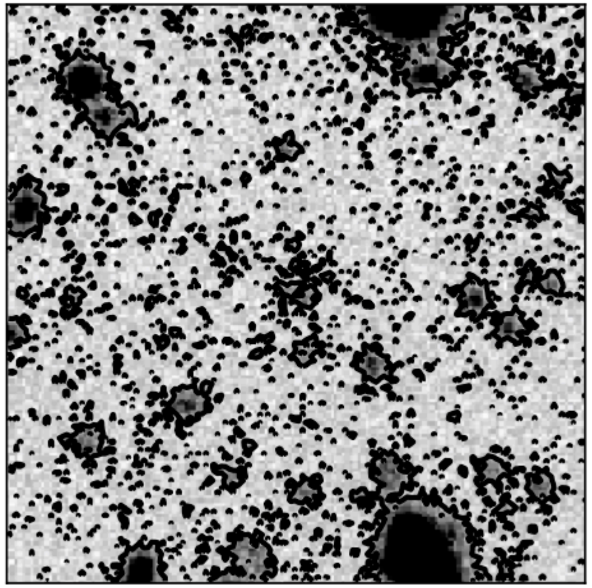


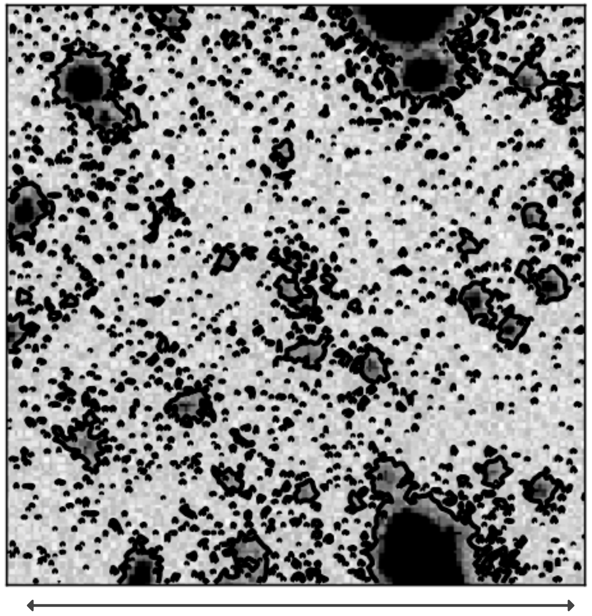
4.5microns



24microns







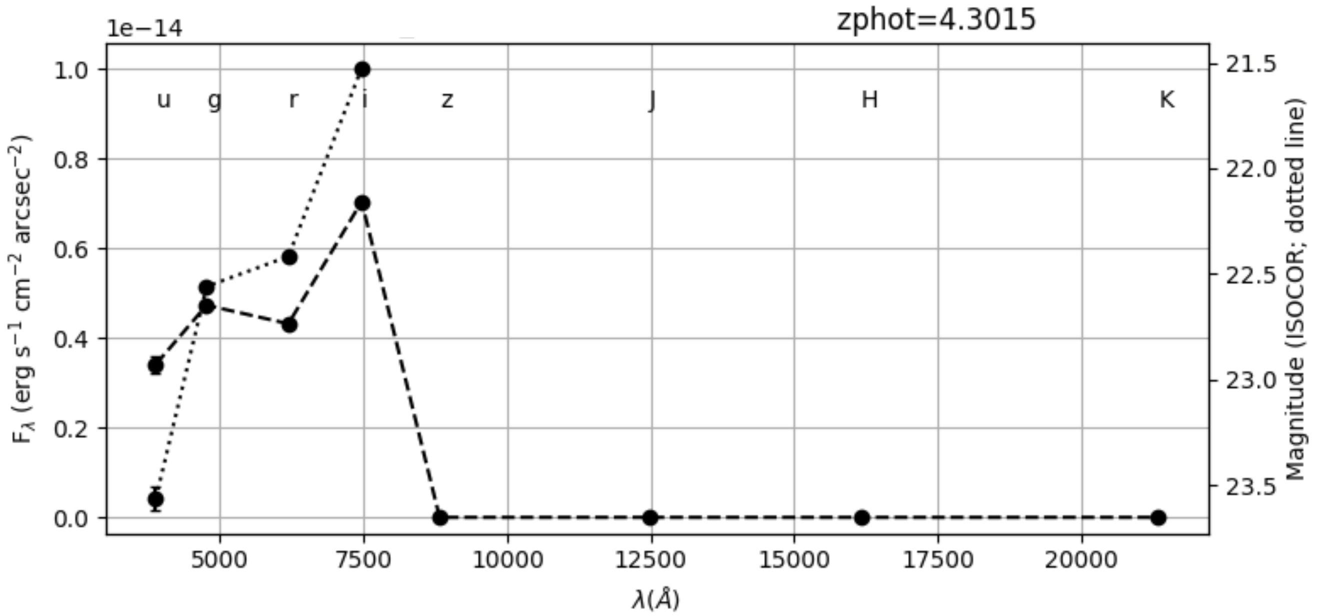
28”

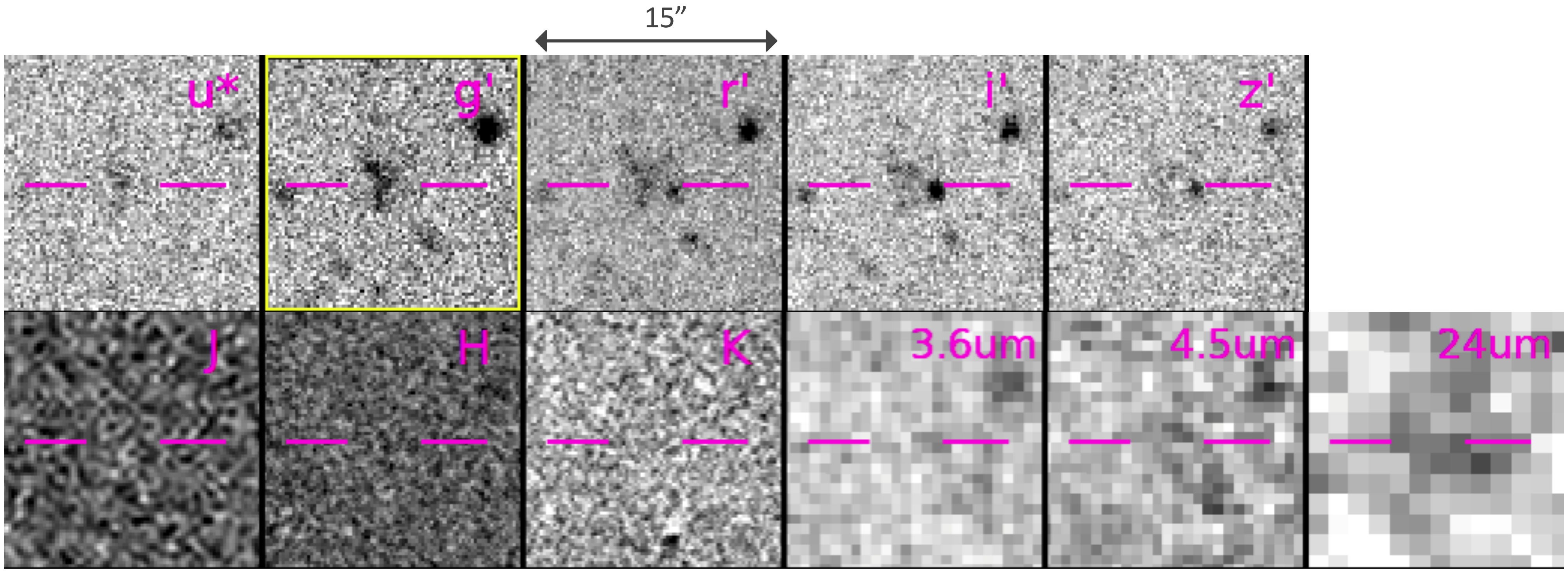
Hibon et al. in prep.

Exciting results

Match in COSMOS2015:

z_{phot} (Laigle) = 4.3





Conclusion

- ATACAMA : innovative and economical systematic search for Lyα nebulae using archival deep broad bands.
- Systematic search in the redshift range $1.7 < z < 7.6$ at least
- Able to probe enormous comoving volumes using existing deep broadband data sets
- Powerful tool : can be used for different kind of sciences.
- Candidate selection under progress
- Limitations : Require spectroscopic confirmation
- Next steps :
    - Large Program with VLT/XSHOOTER

        1- confirm the Lyα emission line detection
        2- direct measure of the velocity shifts of the extended HI gas structures relative to the embedded galaxies in the giant LAB.
    - ALMA proposal for CO & CII detections in the confirmed candidates
- ATACAMA will be publicly release in 2019 for Linux and MacOSx machines.
- **We are searching for collaborators and PhD student!**
  Contact me : phibon@eso.org